Dental age estimation in Somali children using the Willems et al. model

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and Somalia (17%) were most often investigated [5]. The first Somali asylum seekers arrived in Finland in the early 1990s following the mayhem of the civil war in Somalia. In 2016, there were 19,059 first- and second-generation Somalis in Finland [6].

The lack of African reference data, in particular from the Somali population, has been considered problematic in the legal age estimation context [7]. Although, scientifically, increasing evidence exists that ethnic differences are negligible in age estimations based on tooth development [8, 9], more confirmatory proof, especially related to comparisons including black populations, is needed. In fact, few studies of tooth development have been performed among sub-Saharan African populations [10–15]. Only Davidson and Rodd [16] have compared dental age and chronological age between Somali and Caucasian children.

Demirjian's dental age estimation method [17], constructed on a French-Canadian reference sample, is a widely used method to estimate age in children. After staging the development of the seven left mandibular permanent teeth (FDI 31–37), maturity scores are summed up and compared to reference tables or graphs. The age prediction performances of Demirjian's method have been validated in different populations and have resulted in the overestimation of chronological age [13, 18–20]. Willems et al. [18] adapted Demirjian's method using a large Belgian Caucasian reference sample and avoided calculating maturity scores. The Willems et al. model (WM) has been validated in multiple populations (Bangladeshi, Belgian Caucasian, Bosnian-Herzegovian, British Caucasian, Chinese, Former Yugoslav Republic of Macedonian, Malaysian, Serbian, Turkish) and proved to perform better than Demirjian's method [8, 18–19, 21–27]. Over- and underestimations have been reported within a mean error range of −0.58 to 0.39 years. Therefore, the WM was selected for use in the current research.

The aim of the current study was to investigate the age prediction performances of the WM validated on Somali children. An additional purpose was to create a new Somali-specific age estimation model based on the WM and developed on a reference sample of Somali children born and living in Finland. The age prediction performances of the WM and the newly developed Somali model (SM) were compared.

Material and methods

Ethical approval was granted by the Research Ethics Committee of the Hjelt Institute, University of Helsinki (number 02/2010). All individuals eligible to be included in the current study were born in Finland after 1 January 1980. Both of an individual's parents had to be born in Somalia, their mother tongue had to be listed as Somali and their permanent address is Helsinki. According to the Finnish Population Register Centre, 2115 persons fulfilled the above criteria. The research permit was received from the division of Oral Health Care of the Department of Social Services and Health Care in Helsinki (HEL 2015-010918). Retrospectively, 1231 dental panoramic radiographs, used for diagnostic and treatment planning purposes, of 811 criteria-fitting Somali persons were collected from the dental files at the Department of Social Services and Health Care division of Oral Health Care in Helsinki. Only one dental panoramic radiograph per person was included in the study. Subjects were excluded from the study if they were found to have any medical abnormalities affecting dental development (reducing the sample to 808 persons).

The development of the seven left mandibular permanent teeth (FDI 31 to 37) was staged according to Demirjian et al. [17]. In cases with one or more missing index teeth, the contra-lateral homologous teeth were used instead. When all the permanent teeth (31 to 37) were found to be mature (Demirjian stage H, $N = 120$), or when staging could not be performed due to bilaterally missing teeth ($N = 53$), the radiograph was excluded. Therefore, the final studied sample included 635 subjects (311 females, 324 males) in the age range of 4 to 18 years (Table 1).

To test the inter- and intra-observer agreement of the Demirjian staging, 37 panoramic radiographs were re-examined by the principal investigator and a second examiner after 2 months. Kappa and weighted Kappa statistics were used to quantify their agreement.

The Somali sample was used to validate the WM and to establish a Somali-specific age estimation model (SM) based on the WM. The SM was validated using leave-one-out cross-validation. Both models were analysed and compared on their

Table 1 Age and sex distribution of the Somali sample

Age/years	Female (%)	Male (%)	Total
4–4.99	1 (0.32)	3 (0.93)	4
5–5.99	6 (1.93)	7 (2.16)	13
6–6.99	20 (6.43)	19 (5.86)	39
7–7.99	46 (14.79)	33 (10.19)	79
8–8.99	48 (15.43)	42 (12.96)	90
9–9.99	47 (15.11)	50 (15.43)	97
10–10.99	34 (10.93)	48 (14.81)	82
11–11.99	35 (11.25)	41 (12.65)	76
12–12.99	25 (8.04)	35 (10.80)	60
13–13.99	25 (8.04)	23 (7.10)	48
14–14.99	12 (3.86)	12 (3.70)	24
15–15.99	11 (3.54)	6 (1.85)	17
16–16.99	0 (0.00)	3 (0.93)	3
17–17.99	1 (0.32)	2 (0.62)	3
Total	311	324	635

Table 2 Mean error (true age minus predicted age), mean absolute error and root mean squared error validating the Willems et al. model [18] on the collected Somali sample and the Somali model using leave-one-out cross-validation

		Willems model			Somali model		
Sex	N	ME (SD)	MAE (SD)	RMSE (95% CI)	ME (SD)	MAE (SD)	RMSE (95% CI)
F	307	0.20 (1.01)	0.78 (0.67)	1.02 (0.94;1.10)	0.04 (1.01)	0.77 (0.66)	1.01 (0.93;1.09)
M	321	− 0.02 (1.00)	0.77 (0.63)	0.99 (0.92;1.07)	0.05 (1.04)	0.80 (0.67)	1.04 (0.96;1.12)
F + M	628	0.09 (1.01)	0.78 (0.65)	1.01 (0.95;1.06)	0.04 (1.03)	0.79 (0.66)	1.03 (0.97;1.08)

All reported ME, MAE and RMSE values are expressed in years. *F*, female; *M*, male; *ME*, mean error; *SD*, standard deviation; *MAE*, mean absolute error; *RMSE*, root mean square error and *CI*, confidence interval

age prediction performances, calculating the difference between true age and the predicted age. The mean error (ME) presented over- or underestimations (i.e., bias), the mean absolute error (MAE) and root mean squared error (RMSE) quantified the magnitude of the errors (i.e., accuracy). Note that the MAE and RMSE reflect bias as well as lack of precision. The bias and the discrepancy between the age predictions of the WM and SM were evaluated using Wilcoxon signed rank tests. Spearman correlation between true age and the error in age estimation was used to evaluate if the direction and the magnitude of the difference depended on age. All statistical analyses were performed using SAS software, version 9.4 of the SAS System for Windows.

Results

The intra-observer agreement was excellent, with Kappa and weighted Kappa values equal to 0.95 (95% confidence interval (CI) 0.92 to 0.98) and 0.98 (95% CI 0.96 to 0.99), respectively. The inter-observer agreement was also excellent, with Kappa and weighted Kappa values equal to 0.97 (95% CI 0.95 to 1.00) and 0.99 (95% CI 0.98 to 1.00), respectively.

The validated WM overestimated age for males with an ME of − 0.02 years and underestimated age in the total sample (females + males) with an ME of 0.09 years, but these ME values were not significant ($p = 0.27$ and $p = 0.11$, respectively). The WM significantly underestimated the age of females, with an ME of 0.20 years ($p = 0.0006$). The MAE was 0.78 years in females, 0.77 years in males and 0.78 years in females and males combined. The RMSE was 1.02, 0.99, and 1.01 years for females, males and females and males combined, respectively (Table 2).

Validation of the SM resulted in a slight underestimation of age in the three respective sex groups, with MEs varying between 0.04 and 0.05 years, MAEs between 0.77 and 0.80 years and RMSEs between 1.01 and 1.04 years (Table 2).

Comparison between the performance of the WM and the SM revealed statistically significant differences ($p < 0.0001$) in ME 0.16 years in females and − 0.07 years in males. The MAE differed 0.01 years in females ($p > 0.05$) and 0.03 years in males ($p < 0.05$) (Table 3). Figures 1, 2 and 3 present the differences in ME and MAE in years by age categories in females, in males and in females and males combined. The RMSE values from the validated WM and SM were not constant over age and varied between the one-year age-categories (Table 4). The direction of the error (ME) depended on the true age: at younger ages, there was a tendency of overestimation, and at older ages, there was a tendency of underestimation (Spearman correlation between true age and the error in age estimation equalled 0.36, $p < 0.0001$).

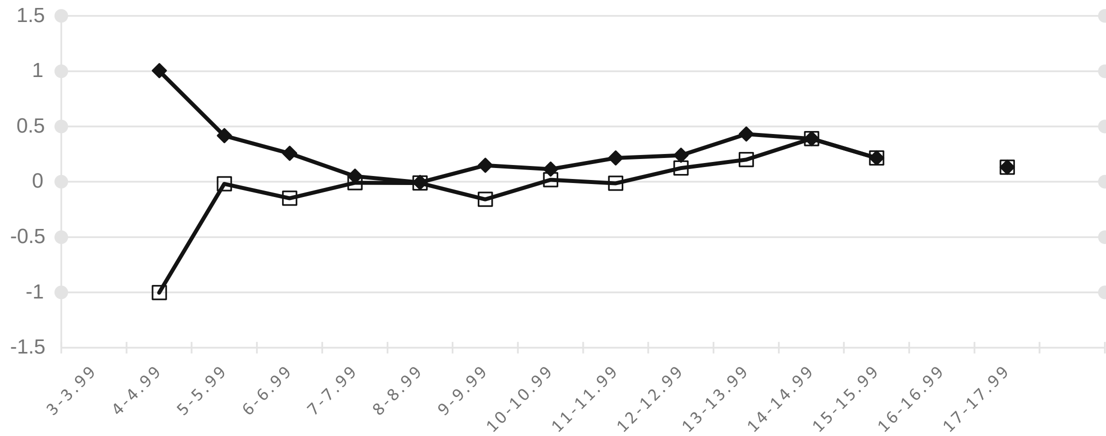
Discussion

The present study on the dental development of Somalis was undertaken to add to the few studies investigating dental development and age-related estimations in sub-Saharan Africans. In our study setting, it was possible to gather reliable data on individuals of ascertained ethnic background and chronological age, which may not necessarily apply to studies

Table 3 Differences in mean error (true age minus predicted age), mean absolute error and root mean square error between the validated Willems et al. model and the Somali model

	Difference bias		Difference accuracy		
Sex	ΔME	p value	ΔMAE	ΔRMSE	p value
F	0.16	< 0.0001	0.01	0.01	0.97
M	− 0.07	< 0.0001	− 0.03	− 0.05	0.0418
F + M	0.05	< 0.0059	− 0.01	− 0.02	0.18

All reported ME, MAE and RMSE values are expressed in years. *F*, female; *M*, male; *ΔME*, difference in mean error; *ΔMAE*, difference in mean absolute error; *ΔRMSE*, difference in root mean square error; *p value*, P value from Wilcoxon signed rank test comparing the differences in true age and predicted age between the two models



performed locally. Phillips and van Wyk Kotze [11] constructed dental age-related tables in children of White and Coloured in South Africa (N = 1006), Indian (N = 234) and Black origin (N = 236; 171 Zulu and 65 Xhosa). The age range of the children they studied was 7 to 16 years. They showed differences in tooth development between the different ethnic groups, but the comparison results were difficult to interpret due to notable differences in the sample sizes and unequal age distributions within the samples. The sexes were not studied separately, and the size of the Black origin group was small. Davidson and Rodd [16] compared dental age with chronological age in Somali (N = 81) and Caucasian (N = 81) children under 16 years of age, resident in Sheffield, UK. Using Demirjian's method [17] to assess dental age, Somali children were significantly more advanced in dental development than the Caucasian children. The usefulness of the result is questionable, however, since it is unclear whether the exact age of Somali children was known, the Somali sample size was small

Table 4 Root mean squared error calculated for females and males from the validated Willems et al. and the Somali models per age category of 1 year. Individuals with stage H were excluded

	Age/years	N	RMSE		ΔRMSE
			Willems et al. model	Somali model	
F	4–4.99	1	−0.19 (−1.89, 1.51)	1.19 (−9.53, 11.91)	−1.38
	5–5.99	3	0.69 (0.20, 1.17)	0.67 (−0.20, 1.55)	0.02
	6–6.99	19	0.45 (0.30, 0.60)	0.61 (0.40, 0.82)	−0.16
	7–7.99	46	0.66 (0.52, 0.80)	0.66 (0.52, 0.79)	0.00
	8–8.99	48	0.82 (0.65, 0.99)	0.82 (0.65, 0.99)	−0.00
	9–9.99	47	0.84 (0.66, 1.01)	1.08 (0.85, 1.30)	−0.24
	10–10.99	34	0.93 (0.70, 1.16)	1.00 (0.75, 1.24)	−0.07
	11–11.99	35	1.05 (0.80, 1.31)	1.12 (0.85, 1.39)	−0.07
	12–12.99	25	1.05 (0.74, 1.35)	0.95 (0.67, 1.22)	0.10
	13–13.99	25	1.29 (0.92, 1.67)	1.03 (0.73, 1.33)	0.26
	14–14.99	12	1.77 (0.98, 2.56)	1.35 (0.75, 1.95)	0.42
	15–15.99	11	1.95 (1.03, 2.86)	1.76 (0.93, 2.58)	0.19
	17–17.99	1	4.12 (32.88, 41.11)	3.99 (−31.83, 39.80)	0.13
M	4–4.99	1	0.62 (−0.19, 1.42)	−0.14 (−1.41, 1.13)	0.76
	5–5.99	7	0.98 (0.36, 1.59)	1.09 (0.40, 1.77)	−0.11
	6–6.99	18	0.80 (0.53, 1.07)	0.79 (0.51, 1.06)	0.01
	7–7.99	33	0.80 (0.60, 1.00)	0.83 (0.62, 1.04)	−0.03
	8–8.99	42	0.72 (0.56, 0.88)	0.67 (0.52, 0.81)	0.05
	9–9.99	50	0.86 (0.69, 1.04)	0.90 (0.72, 1.08)	−0.04
	10–10.99	48	0.98 (0.78, 1.18)	1.02 (0.81, 1.23)	−0.04
	11–11.99	41	0.93 (0.73, 1.14)	0.93 (0.72, 1.14)	0.00
	12–12.99	35	1.24 (0.94, 1.55)	1.34 (1.02, 1.67)	−0.10
	13–13.99	23	1.03 (0.72, 1.35)	1.19 (0.83, 1.55)	−0.16
	14–14.99	12	0.88 (0.49, 1.27)	1.03 (0.57, 1.48)	−0.15
	15–15.99	6	1.78 (0.52, 3.04)	1.85 (0.54, 3.16)	−0.07
	16–16.99	3	2.12 (−0.63, 4.87)	2.24 (−0.68, 5.14)	−0.12
	17–17.99	2	2.86 (−3.29, 9.00)	3.00 (−3.45, 9.44)	−0.14

F, females; *M*, males; *RMSE*, root mean squared error; *ΔRMSE*, difference in root mean square error. 95% confidence intervals for the RMSE are given between brackets

was reduced for this comparison from 635 (Table 1) to 628 (Table 2) subjects.

The good performance of validating the WM on the collected Somali children could partially be explained by the larger number of subjects in the Belgian Caucasian reference sample (WM, N = 2116, SM, N = 635) [18]. Larger samples tend to be a more accurate reflection of the population; hence, their sample means are more likely to be closer to the population mean. Even a small change in the number of subjects included in the considered sample can affect the outcome. To obtain an equal number of females in the comparison of error in age prediction between the WM and SM, in the current study, the validation sample was reduced from 311 to 307 subjects, increasing the ME of the WM from 0.20 to 0.21 years.

The age prediction performances were not constant over age (Table 4). The higher the true age, the larger the absolute error was (rho = 0.30, $p < 0.0001$). The direction of the error depended on the true age: at younger ages, there was a tendency of overestimation and at older ages a tendency of underestimation (Spearman correlation between true age and the error in age estimation equalled 0.36, $p < 0.0001$). This is a classical finding in the application of regression models [30]. Since the present study was considering Somali children living in Finland and not in their home country, a possible influence of environmental factors might have an effect on dental maturity. Related to nutrition, Jääsaari et al. [31] longitudinally studied the association between dental maturity and body mass index (BMI) in an unselected group of Finnish children at the ages of 6 and 12 years. Tooth development was registered according to Demirjian et al. [17] from the seven left mandibular permanent teeth (FDI 31–37) on 108 dental panoramic radiographs. Groups of delayed, average and advanced dental development were established and compared with normal and high BMI groups; energy intake was also studied with food records. They found no significant difference in BMI between delayed, normal or advanced dental maturity groups. However, the dental age in the advanced dental maturity group was advanced by 0.6 to 1.0 years when compared with the chronological age, and this group of children had a higher energy intake when compared with the average and delayed dental maturity groups ($p = 0.004$). They conclude that there might be an association between advanced dental maturity and BMI. A previous study has also reported advanced dental development in overweight or obese children [32]. Converse results demonstrating a delay of dental development in underweight children have not, to the best of our knowledge, been published. Elamin and Liversidge [33] studied dental development in malnourished and normal BMI groups of young Arabs in Sudan. The subjects ($N = 2115$) were between 2 and 22 years old. No significant difference in tooth formation was detected between the two groups. This study showed that teeth have substantial biological stability and are insulated from nutritional deprivation.

As a relative limitation of the study, the subjects included here had undergone dental panoramic radiography for valid clinical reasons related to dental health and deviations from normal occlusal development. Except for some longitudinal studies [31, 34, 35], this is typical for most, if not all, recent studies, making them comparable with each other. Poor dental health that leads to precocious extractions of primary teeth has been shown to speed up the eruption and alter the crown-to-root ratio of the succedaneous permanent teeth [36, 37]. Nevertheless, dental developmental status is less affected than eruption status in subjects suffering from the premature loss of primary teeth [17]. Many of the children forming the material of the present study are likely to have exhibited malocclusion, since 95% of dental panoramic radiographs taken of children aged 7–12 years in the municipal healthcare centres in the City of Helsinki are taken for reasons related to orthodontics [38]. Although the study subjects were not analysed here for the presence or type of orthodontic problems, it is worth noting that individuals with discrepancies in jaw size have been shown to display advanced dental maturity in comparison to children with non-skeletal orthodontic problems; the difference reaches statistical significance in girls with mandibular prognathism [2].

Conclusion

The small differences in age prediction performances of the WM and the constructed SM reflect the usefulness of the Belgian population as a reference for forensic age predictions in Somali children living in Finland. The study also provides further support for the universal application of the WM to estimate age.

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Compliance with ethical standards

Ethical approval was granted by the Research Ethics Committee of the Hjelt Institute, University of Helsinki (number 02/2010).

Conflicts of interest The authors declare that they have no conflicts of interest.

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